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DETERMINANTS VIA MATHEMATICAL INDUCTION[1]

FORBES B. WILEY[2]

This paper reports three efforts. The first is to attain more than the usual directness in the introductory treatment of determinants; the second is to secure for the college freshman other than the classical examples of the use of mathematical induction; and the third is to illustrate to these same students how a liberal yet careful use of symbols may contribute to economy in expression and clarity of thought.

The degree of success of the first effort may be judged by the reading of the theorems 4.1 to 4.10, that of the second by the reading of the paper in full. In this there is a fairly strict adherence to the plan of furnishing illustrations of the use of mathematical induction even at the occasional cost of sacrificing an available simpler method of proof. The experienced reader will notice this in particular in theorems 4.11 and 4.12. The third effort is made an integral part of the whole paper. One might note here the concise expression for the solution of a system of n linear equations in n unknowns by the introduction of a determinant of order $n + 1$.

Introductory sections are given on mathematical induction and on definitions and symbols. For the sake of economy in space, numerical illustrations and short-cuts in determining the value of a determinant are omitted. These can be supplied from almost any text in college algebra.

It is the author's experience that freshmen who are somewhat above the average in mathematical ability can, with a small amount of direction, read this paper.

1. M.I.; MATHEMATICAL INDUCTION

1.1: A necessary condition for the use of the method called mathematical induction in proving a theorem is that the theorem be a composite statement asserting the truth of each member of a sequence $\{S_n\}$ of individual statements formed by n taking on the values $1, 2, 3, \cdots, r, \cdots$, r being some one particular value of n. We shall call this condition 1.1.

1.2: We next assume that the theorem does hold true for some one particular value of n, say r. We designate this assumption by 1.2.

1.3: It is necessary to show that a consequence of **1.2** is that the theorem holds true for $r = n + 1$, the next higher value for n than the one used in 1.2. We call this 1.3.

1.4: Another necessary condition in the proof is that the theorem can be shown to be true for some one value of n, perhaps 1, 2, or 3, a value which can serve as the r in 1.2. We shall designate this as 1.4.

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1.5: The satisfying of the above conditions is sufficient for establishing the truth of the theorem for each successive value of n equal to or greater than the value used in 1.4.

1.6: If the value used for n in 1.4 is not the smallest one permissible in the statement of the theorem, these smaller values must be checked before the theorem is fully established. We shall designate this final check as 1.6.

1.7: We give here a classical example of the use of M.I., in proving a theorem. In this theorem, we shall use the sigma notation for a sum. (See 2.3.)

THEOREM:

$$\sum_{j=1 \text{ to } n} (2j - 1) = n^2, \quad \text{for all integral values of } n.$$

1.1 is satisfied, thus we may use M.I. method of proof.

For 1.2 we write:

$$\sum_{j=1 \text{ to } r} (2j - 1) = r^2.$$

To each side of this equation add $2r + 1$.

This results in

$$\sum_{j=1 \text{ to } r+1} (2j - 1) = r^2 + 2r + 1.$$

This, in turn, equals $(r + 1)^2$, which satisfies 1.3.

Setting $n = 1$ in the statement of the theorem, we obtain

$$1 = 1^2, \text{ which satisfies 1.4.}$$

1.5 and 1.6 are also satisfied and the truth of the theorem is established.

2. Definitions and Symbols

2.1: A; A^n; B; C; $\{A^n\}$, $n = 1, 2, 3, \cdots, r, \cdots$.

The square arrangement,

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} & a_{14} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & \cdots & a_{3n} \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdot \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & \cdots & a_{nn} \end{vmatrix},$$

of n^2 numbers a_{ij}, i and $j = 1$ to n, enclosed, as indicated, by parallel vertical bars, is called *a determinant of the nth order*. Each a_{ij} is called *an element* of the determinant, the first subscript designating the row, and the second subscript the column, in which the element is located. For sake of brevity, this square array is often represented by

$$\left| \begin{matrix} a_{ij} \\ i, j, = 1 \text{ to } n \end{matrix} \right|.$$

We shall represent it by A, or A^n, visualizing in each case, however, the square arrangement above.

We shall resort to letters B and C to represent other determinants, as the necessity for additional designations arises.

Since n may have any positive integral value, we have defined the sequence of determinants $\{A^n\}$, $n = 1, 2, 3, \cdots, r, \cdots$.

2.2: A_{hk}, A_{hkst}.

We shall designate the determinant of order $n - 1$, obtained by deleting the hth row and the kth column of A^n, by the symbol, A_{hk}. When rows numbered h and s, and columns numbered k and t are deleted from A^n, the resulting determinant of order $n - 2$ will be designated by A_{hkst}.

2.3: $\sum$

We shall use the Greek letter sigma, $\sum$, to represent a sum. We give two examples, as follows:

$\sum_{j=1 \text{ to } 5} (2j - 1)$ stands for the sum of five terms:

$$(2\cdot 1 - 1) + (2\cdot 2 - 1) + (2\cdot 3 - 1) + (2\cdot 4 - 1) + (2\cdot 5 - 1).$$

This, upon simplification, becomes:

$$1 + 3 + 5 + 7 + 9.$$

For our second example we give:

$\sum_{j=1 \text{ to } 4} (-1)^{j+1} a_{1j} A_{1j}$, a sum of four terms as follows:

$(-1)^{1+1} a_{11} A_{11} + (-1)^{2+1} a_{12} A_{12} + (-1)^{3+} a_{13} A_{13} + (-1)^{4+1} a_{14} A_{14}$, or, more simply,

$$a_{11} A_{11} - a_{12} A_{12} + a_{13} A_{13} - a_{14} A_{14}.$$

2.4: (A), (A^n).

With each A, or A^n, is associated a number, represented by (A), or (A^n), which is called the *value of the determinant*. We define this *value* as follows:

For A^1, i.e., the determinant $| a_{11} |$, of the first order, (A^1) shall be simply the number a_{11}.

For A^n, $n > 1$, (A^n) shall be defined as

$$\sum_{j=1 \text{ to } n} (-1)^{j+1} a_{1j} (A_{1j}).$$

This is known as the *Laplace expansion of* (A) *by the first row*. We shall have occasion to refer to it as the *first step in computing* (A). If in this first step, each (A_{1j}) is replaced by its first step in computing its value, we have then the *second step in computing* (A). Continuing in this way, the *nth step* gives us a sum of products of elements, *the complete development of* (A).

2.5: $\rightarrow$

We shall use → as the symbol of implication.

3. Transformations

We shall have occasion to alter A by a limited number of changes, called *transformations*, into a new determinant B. These changes with their corresponding symbols are listed below.

3.1: $[hk]$

The interchange of the hth and the kth rows of a determinant is represented by the symbol $[hk]$, thus: $[hk]\, o\, A = B \rightarrow a_{hj} = b_{kj}$, $a_{kj} = b_{hj}$, while $a_{ij} = b_{ij}$ for all values i other than h and k. $j = 1$ to n in all cases. We read this: "If the interchange of the hth and the kth rows of A gives B, then $a_{hj} = b_{kj}$, etc."

3.2: $[h]$

The moving of the hth row into position as first row, while the relative order of all other rows remains unchanged, is represented by the symbol $[h]$, thus:

$$[h]\, o\, A = B \rightarrow a_{hj} = b_{1j},\ a_{ij} = b_{i+1\, j} \text{ for } i < h;\ a_{ij} = b_{ij} \text{ for } i > h;$$
$$j = 1 \text{ to } n \text{ in all cases.}$$

3.3: $[hh']$

The interchange of rows with columns, maintaining the original order of the elements in each, is represented by the symbol $[hh']$ thus:

$$[hh']\, o\, A = B \rightarrow a_{ij} = b_{ji};\ i, j = 1 \text{ to } n.$$

3.4: $[mk + h]$

The changing of the hth row, and that row only, by adding to each of its elements a constant m times the corresponding element (the element in the same column) in the kth row is represented by the symbol $[mk + h]$, thus:
$[mk + h]\, o\, A = B \rightarrow b_{hj} = a_{hj} + m\, a_{kj}$; $b_{ij} = a_{ij}$, $i \neq h$, $j = 1$ to n in all cases.

3.5: $[m \cdot h]$

The changing of the hth row, and that row only, by multiplying each of its elements by a constant m is represented by $[m \cdot h]$, thus: $[m \cdot h]\, o\, A = B \rightarrow b_{hj} = m\, a_{hj}$, $b_{ij} = a_{ij}$ for $i \neq h$; $j = 1$ to n in all cases.

3.6: Wherever any of the above are used with letters carrying primes, such primed letters shall refer to columns instead of rows. (cf. 3.3).

4. Theorems on Determinants

4.1: For every A^n, the number (A^n) is unique.

We prove this by M.I.

Condition 1.1 is met by the definition 2.1.

We write

$$(A^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{j+1} a_{1j} (A^r_{1j}).$$

Since 1.2 is satisfied by every (A^r_{1j}), (A^{r+1}) is the finite sum of products of unique numbers and thus is itself unique, satisfying 1.3. 1.4 is met by definition of (A^1) in 2.1. Thus 1.5 and 1.6 are met and the theorem established.

4.2: The complete development of (A^n) is a sum containing $n!$ terms.

Condition 1.1 is met and we use M.I.

We write:

$$(A^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{j+1} a_{1j}(A^r_{1j}),$$

where, by 1.2, each (A^r_{1j}) is a sum containing $r!$ terms, in its complete development. Since (A^{r+1}) contains $r + 1$ such terms, its complete development contains $(r + 1) \cdot r!$, or $(r + 1)!$ terms. This meets condition 1.3. (A^1) has, by 2.4, 1! term. This meets 1.4 and, in turn, 1.5 and 1.6.

4.3: $[k\ h]\ o\ A^n = B^n \rightarrow (B) = -(A)$.

We first establish, not by M.I., the following lemma:

Lemma: $[2\ 1]\ o\ A^n = B^n \rightarrow (B) = -(A)$.

A representative term in the first step in computing the (A) of our lemma is

$$(-1)^{1+j} a_{1j}(A_{1j}),$$

while a representative term in the first step in computing (A_{1j}) is

$$(-1)^e a_{2k}(A_{1j2k}),$$

where $e = 1 + k$ if $k < j$, and $1 + k - 1$ if $k > j$. Thus a representative term in the second step in computing (A) is

$$(-1)^f a_{1j} a_{2k}(A_{1j2k}),$$

where $f = j + k + 2$ if $k < j$, and $j + k + 1$ if $k > j$.

The corresponding representative term in the second step in computing (B) is

$$(-1)^g b_{1k} b_{2j}(B_{1k2j}).$$

Since the order of the choice of j and k in computing (B) is the reverse of what it was in computing (A), we have

$$g = j + k + 1 \text{ if } k < j, \qquad \text{and } j + k + 2 \text{ if } k > j.$$

Thus we have

$$(-1)^g = -(-1)^f; \qquad b_{1k} = a_{2k}\ ; \qquad b_{2j} = a_{1j}\ ; \qquad (B_{1k2j}) = (A_{1j2k}),$$

making these corresponding general terms differ in signs, and in signs only. Since there is a one-to-one correspondence between the respective terms in the computations of (A) and (B), what is true of the representative corresponding terms is true of all corresponding terms, namely: the one is the negative of the other. This, then, is true also of their sums, and the Lemma is established.

We now turn to the proof of our general theorem 4.3.

1.1 is satisfied and we shall use M.I. We write, as usual,

$$(A^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{j+1} a_{1j}(A^r_{1j}).$$

We use (A^r_{1j}) for 1.2, thus our theorem holds for (A^{r+1}) in all cases excepting where the first and some other than the second rows are involved, providing, of course, that we can satisfy 1.4. We can handle

$$k \neq 1 \text{ or } 2; \qquad [1\ k]\ o\ (A^{r+1}) = (B^{r+1}) \text{ as follows:}$$

$$[1\ 2]\ o\ (A) = (C); \qquad [2\ k]\ o\ (C) = (D); \qquad [2\ 1]\ o\ (D) = (B).$$

$$(C) = -(A), \qquad (D) = -(C), \qquad (B) = -(B),$$

by Lemma, 1.2 above, and Lemma, respectively. Thus 1.3 is satisfied. 1.4 is met by using (A^2), where the Lemma applies. The theorem is meaningless for A^1, thus we have met conditions 1.5 and 1.6.

4.4: $[h]\ o\ A^n = B^n \rightarrow (B) = (-1)^{h-1}(A)$.

1.1 is satisfied and we shall use M.I.

The theorem is trivial if $h = 1$, and is Lemma of 4.3 if $h = 2$.

We shall consider, then, that $h > 2$.

Following our usual custom, we write

$$(A^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{j+1} a_{1j}(A^r_{1j}).$$

The hth row of A^{r+1} is the $(h-1)$th row of A^r_{1j}, for every value of j.

Let $[h-1]\ o\ A^r_{1j} = C^r_{1j}$, then $(C^r_{1j}) = (-1)^{h-2}(A^r_{1j})$, by 1.2.

If

$$(C^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{j+1} c_{1j}(C^r_{1j}),$$

then C^{r+1} is A^{r+1} changed by moving its hth row into position as second row, the relative order of all other rows being unchanged. Since $c_{1j} = a_{1j}$, we have, at this point, $(C^{r+1}) = (-1)^{h-2}(A^{r+1})$. By the Lemma of 4.3, $(B^{r+1}) = -(C^{r+1})$, thus $(B^{r+1}) = (-1)^{h-1}(A^{r+1})$ and condition 1.3 is established. Our theorem is true for A^2 by the Lemma of 4.3, thus 1.4, and also 1.5 and 1.6 are met, and the proof completed.

We give three corollaries to 4.4.

4.4.1: (A) may be written as an expansion in terms of the elements of any row h in the following manner:

$$(A) = \sum_{j=1 \text{ to } n} (-1)^{j+h} a_{hj}(A_{hj}).$$

For the proof use $[h]\ o\ A = B$, then we have, by 4.4,

$$(A) = (-1)^{h-1}(B),$$

where

$$(B) = \sum_{j=1 \text{ to } n} (-1)^{j+1} b_{1j}(B_{1j}), \text{ by 2.4.}$$

But $b_{1j} = a_{hj}$ and $(B_{1j}) = (A_{hj})$, thus

$$(A) = (-1)^{h-1} \sum_{j=1 \text{ to } n} (-1)^{j+1} a_{hj}(A_{hj}),$$

which, in turn, reduces to the statement of 4.4.1.

4.4.2: All of the terms in the complete expansion of (A) which involve the particular element a_{hj} as a factor are found from the complete expansion of (A_{hj}) in the expression.

$$(-1)^{h+j} a_{hj}(A_{hj}).$$

This is seen from the fact that in 4.4.1 the jth column is deleted from A for every A_{hj}, thus the only place for a_{hj} to appear as a factor is as the coefficient of (A_{hj}), as stated in the corollary.

4.4.3: (A) may be written as an expansion in terms of the elements of any column k in the following manner:

$$(A) = \sum_{i=1 \text{ to } n} (-1)^{i+k} a_{ik}(A_{ik}).$$

This sum satisfies the necessary condition for (A) of containing all of the terms which involve each of the elements of the kth column, as factors, thus the elements of every column. Since there are $n[(n-1)!]$, or $n!$, terms, with no repetitions, this sum is a sufficient condition for the value of (A).

4.5: $[h\ h']\ o\ A = B \rightarrow (B) = (A)$.

1.1 holds and we shall use M.I. in the proof.

We write the development of (A^{r+1}) by the first row and that of (B^{r+1}) by the first column, as follows:

$$(A^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{1+j} a_{1j}(A^r_{1j});$$

$$(B^{r+1}) = \sum_{i=1 \text{ to } r+1} (-1)^{i+1} b_{i1}(B^r_{i1}).$$

For the corresponding terms in the two sums, that is, where the j of the first equals the i of the second, we have

$$(-1)^{1+j} = (-1)^{i+1},$$

and, also, $a_{1j} = b_{i1}$, since $i = j$, and the first row of A is the first column of B. $(A^r_{1j}) = (B^r_{i1})$, by 1.2. Thus the terms in the sum for (A^{r+1}) are equal, respectively, to their corresponding terms in the sum for (B^{r+1}) and the condition 1.3 is satisfied. 1.4 is met by testing A^2, the theorem is trivial for A^1, therefore 1.5 and 1.6 are met.

4.5.1: If in any theorem involving the value of a determinant, the word "row" is replaced by the word "column," and vice versa, a new theorem which we may call the dual of the original, is obtained.

The proof of this follows immediately from 4.5.

We now state five theorems whose proofs may be handled together. Where m occurs, it may be taken as any positive or negative number. Note that 4.6 is a special case of 4.7, also of 4.9.

4.6: If A is such that $a_{hj} = 0, j = 1$ to $n, \rightarrow (A) = o$.

4.7: If $[m \cdot h]\ o\ A = B \rightarrow (B) = m(A)$.

4.8: If $[mk + h]\ o\ A = B, k \neq h, \rightarrow (B) = (A)$.

4.9: If A is such that $a_{hj} = m\ a_{kj}, j = 1$ to $n, h \neq k, \rightarrow (A) = 0$.

4.10: If A^n, B^n, and C^n are such that $a_{hj} = b_{hj} + c_{hj}$, while for $i \neq h$, $a_{ij} = b_{ij} = c_{ij}, \rightarrow (A) = (B) + (C)$.

1.1 is met in each case and we shall use M.I.

Let P_i, $i = 1$ to 5, be the conditions imposed, or the transformations used, upon the determinants in theorems 4.6 to 4.10, respectively. We write:

$$(A^{r+1}) = \sum_{j=1 \text{ to } r+1} (-1)^{s+j} a_{sj}(A^r_{sj}),$$

where the fixed row s is not the h or the k of any of the theorems.

The appropriate P_i holds for (A^r_{sj}) of each theorem, by 1.2. They are, in each case, properties which are distributive and thus hold for the sums, i.e., for (A^{r+1}), satisfying 1.3. By test, 1.4 is met by A^2 for all five theorems. 1.5 and 1.6 are now satisfied and the proofs established.

4.11: Consider the sequence $\{S_n\}$, $n = 1, 2, \cdots, r, \cdots$ of systems of n non-homogeneous equations, linear in the n quantities x_j, as follows:

$$\{S_n\}: \sum_{j=1 \text{ to } n} a_{ij}x_j = a_{i\,n+1}; \qquad i = 1 \text{ to } n;$$

also the following determinant of order $n + 1$:

$$A^{n+1}: \left| \begin{matrix} a_{ij} \\ i, j = 1 \text{ to } n + 1 \end{matrix} \right|,$$

where a_{n+1j}, $j = 1$ to $n + 1$; are arbitrary constants, and all other numbers a_{ij} are as defined in the particular system $\sum_{j=1 \text{ to } n}$. We then have the theorem:

$$\{S_n\}: \sum_{j=1 \text{ to } n} a_{ij}x_j = a_{i\,n+1}; \qquad i = 1 \text{ to } n; \qquad (A_{n+1\,n+1}) \neq 0,$$
$$\rightarrow x_j = (-1)^{n-j}(A_{n+1\,j}) \div (A_{n+1\,n+1}), \qquad j = 1 \text{ to } n$$

1.1 is met and we use M.I. in the proof, as follows:
Take $r + 1$ as a particular value of n, giving the system of equations

$$\sum_{j=1 \text{ to } r+1} a_{ij}x_j = a_{i\,r+2}; \qquad i = i \text{ to } r + 1; \qquad (A_{r+2\,r+2}) \neq 0.$$

Since by 4.4.1,

$$(A_{r+2\,r+2}) = \sum_{j=1 \text{ to } r+1} (-1)^{h+j} a_{hj}(A_{h\,j\,r+2\,r+2}),$$

for any h, and, by hypothesis, $(A_{r+2\,r+2}) \neq 0$, then, by 4.6 at least one $(A_{h\,j\,r+2\,r+2}) \neq 0$, for each value of j. Without loss of generality, the equations of the system S_{r+1} may be arranged so that $(A_{r+1\,k\,r+2\,r+2}) \neq 0$, where k is any specific value of j. Consider S_{r+1} to be arranged as just stated, also with the terms $a_{ik}x_k$ moved to the right of the equality sign. For sake of convenience in notation, rename the terms so that the equations, as now written, are

$$S_{r+1}: \sum_{j=1 \text{ to } r} b_{ij}y_j = -b_{i\,r+1}y_{r+1} + b_{i\,r+2}, \qquad i = 1 \text{ to } r + 1.$$

By 1.2 our theorem holds for the first r of these equations. Thus each y_j, $j = 1$ to r, is expressible as the quotient of two determinants, the numerator determinant in each case having the binomials $-b_{i\,r+1}y_{r+1} + b_{i\,r+2}$ as the elements of the last column. This gives, by 4.10,

$$y_j = (-1)^{r-j}[-(B_{r+1\,j\,r+2\,r+2})y_{r+1} + (B_{r+1\,j\,r+2\,r+1})] \div (B_{r+2r\,+2\,r+1\,r+1}).$$

The $r + 1$st equation of S_{r+1}, namely,

$$\sum_{j=i \text{ to } r} b_{r+1\,j}y_j = -b_{r+1\,r+1}y_{r-1} + b_{r+1\,r+2},$$

must be satisfied by these values of y_j. Substitution, clearing of fractions and regrouping, give

$$\Big[\sum_{j=1 \text{ to } r} (-1)^{r+1-j} b_{r+1\,j}(B_{r+1\,j\,r+2\,r+2}) + b_{r+1\,r+1}(B_{r+2\,r+2\,r+1\,r+1})\Big]\, y_{r+1}$$

$$= \sum_{j=1 \text{ to } r} (-1)^{r+1-j} b_{r+1\,j}(B_{r+1\,j\,r+2\,r+1}) + b_{r+1\,r+2}(B_{r+2\,r+2\,r+1\,r+1}).$$

This condenses into the form

$$\sum_{j=1 \text{ to } r+1} (-1)^{r+1-j} b_{r+1\,j}(B_{r+1\,j\,r+2\,r+2})y_{r+1}$$

$$= \sum_{j=1 \text{ to } r-2,\, j\neq r+1} (-1)^{r+1-j} b_{r+1\,j}(B_{r+1\,j\,r+2\,r+1}),$$

with the sign of the last term changed to +. The above equation is

$$(B_{r+2\,r+2})y_{r+1} = (B_{r+2\,r+1}), \text{ by 2.4.}$$

Changing back to x_k and the A notation, we have

$$(A_{r+2\,r+2})x_k = (-1)^{r+1-k}(A_{r+2}\,k).$$

Recalling that x_k is any specific x_j, we have met condition 1.3.

1.4 is met by actual test in S_2, thus 1.5 and 1.6 are satisfied and the proof completed.

4.12 $\{S_n\}: \sum_{j=i \text{ to } n} a_{ij}x_j = 0; \quad i = 1 \text{ to } n; \quad (A^n) \not\equiv 0$

$\rightarrow (A^n) = 0$ is the eliminant of the system of equations S_n.

For the elementary reader, we might state this verbally as follows: If $\{S_n\}$ is a sequence of systems of n equations, homogeneous and linear in the n quantities x_j, and if the determinant A^n has a value not identically zero, then this determinant set equal to zero in value gives the relationship existing among the quantities a_{ij}, resulting from eliminating all quantities x_j from the system of equations S_n.

1.1 is satisfied and we shall use M.I. in the proof.

By 1.2 we assume that the theorem holds for S_r. We set up

$$S_{r+1}: \sum_{j=1 \text{ to } r+1} a_{ij}x_j = 0; \quad i = 1 \text{ to } r+1; \quad (A^{r+1}) \not\equiv 0.$$

Let k be some one of the values of j. Move the kth term of each equation of S_{r+1} into position of next to the last term, keeping the relative order of all other terms unchanged. From the first r equations so written, define $\underline{S}_r$ as follows:

$$\underline{S}_r: \sum_{j=1 \text{ to } r} b_{ij}y_j = 0; \quad i = 1 \text{ to } r;$$

where

$$b_{ij}y_j = a_{ij}x_j, \text{ for } j = 1 \text{ to } k-1;$$

$$b_{ij}y_j = a_{i\,j+1}x_{j+1}, \text{ for } j = k \text{ to } r-1; \text{ and}$$

$$b_{ir}y_r = (a_{ik}x_k + a_{i\,r+1}x_{r+1})\cdot 1. \text{ Thus } y_r = 1.$$

Before applying 1.2 to this system, we must show that $(B^r) \not\equiv 0$.

Let $[x_{r+1} \cdot (r + 1)'] \; o \; A^{r+1} = C$.

By hypothesis, and 4.7, $(C^{r+1}) \not\equiv 0$.

Let $[x_k \cdot k' + (r + 1)'] \; o \; C = D$.

By 4.8, $(D) = (C)$, and thus (D) is not identically zero. It follows that, for every k, $(D_{ik}) \not\equiv 0$, for at least one value of i. Consider the equations in y to be written so that $(D_{r+1\,k}) \not\equiv 0$. Thus $(B^r) = (D_{r+1\,k})$, and, in turn, is not identically zero. We may now say that, by 1.2, $(B^r) = 0$ is the eliminant of the equations in y.

By 4.10, $(B^r) = (C^r) + (D^r)$, where $(C^r) = (-1)^{r-k} x_k(A_{r+1\,r+1})$, and $(D^r) = x_{r+1}(A_{r+1\,k})$. Thus we have $(-1)^{r-k} x_k(A_{r+1\,r+1}) + x_{r+1}(A_{r+1\,k}) = 0$, and $x_k = [(-1)^{r-1-k}(A_{r+1\,k}) \div (A_{r+1\,r+1})] \cdot x_{r-1}$.

Since this discussion holds true for any $j = k$, we may replace k by j in the above and substitute the resulting values of x_j in the last equation of S_{r+1}, namely in the equation

$$\sum_{j=1 \text{ to } r+1} a_{r+1\,j} x_j = 0.$$

This substitution gives us the result

$$\sum_{j=i \text{ to } r} (-1)^{r+1-j} a_{r+1\,j}(A_{r+1\,j}) x_{r+1} + a_{r+1\,r+1}(A_{r+1\,r+1}) x_{r+1} = 0.$$

Since the x_j quantities in the equations may be considered as arbitrary values, x_{r+1} is not zero. Division by x_{r+1} and then collection of terms gives

$$\sum_{j=i \text{ to } r+1} (-1)^{r+1-j} a_{r+1\,j}(A_{r+1\,j}) = 0.$$

This meets condition 1.3.

The elementary algebraic process of elimination of x_1 and x_2 from S_2 results in meeting condition 1.4. Conditions 1.5 and 1.6 are thus automatically met and the proof completed.

OBSERVATIONS ON THE MICHIGAN FLORA, II:[1] SOME PLANTS NEW OR RARE IN EMMET, CHEBOYGAN, AND MACKINAC COUNTIES, MICHIGAN

EDWARD G. VOSS[2]

In the course of four years of collecting in the region of the Straits of Mackinac in northern Michigan, I have discovered a few species of plants in counties from which they do not appear to have been previously reported. In addition, localities for certain species previously reported from only one or two stations have been discovered and seem worthy of mention.

Emmet and Cheboygan Counties, which share the south side of the Straits, have been covered so thoroughly by members of the University of Michigan Biological Station at Douglas Lake (Cheboygan Co.) that new records from these counties carry a little more significance than were they to come from a relatively unexplored region of the state. Gates and Ehlers (1948, p. 46) report 1226 species and varieties from the two counties; 938 of these are known from Emmet County, and 1120 from Cheboygan County. The present notes add five to the Emmet County list, and one to the Cheboygan County list; of these six, four are new to the total list.

Mackinac Island has been studied by Dodge (1913 and 1921) and by Potzger (1941), although the mainland of Mackinac County, which extends along the north side of the Straits, has received relatively little botanical attention. The records which follow for Mackinac County are either from the mainland or from Green Island, which is little more than a sand and stone bar less than half a mile long, rising from the Straits of Mackinac about half a mile from Pt. La Barbe, the nearest mainland. The island supports over a hundred species of vascular plants, five of which are here reported from the county for the first time. Four of the plants newly reported for Mackinac County in a survey of the St. Ignace Causeway (Voss, 1948) occur also on Green Island: *Diplotaxis muralis* (L.) DC.; *Aster junceus* Ait.; *Tanacetum huronense* Nutt.; and *Hieracium florentinum* All.

Green Island may be seen on Chart 6 and Coast Chart 60 of the Survey of the Northern and Northwestern Lakes (War Department, Corps of Engineers) and on the advance sheet (planimetric) for the south half, St. Ignace-Moran Quadrangle, State of Michigan, published by the U. S. Geological Survey (not a topographic map). Most maps naturally do not indicate it because of its small size.

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[1] The first in this series, "A Survey of the St. Ignace Causeway (Mackinac County)," appeared in the *Denison University Bulletin, Journal of the Scientific Laboratories*, 41: 39–45, December 1948.

[2] Class of 1950, Denison University. This paper was presented before the Plant Sciences section of the Ohio Academy of Science, April 22, 1949.

Previous records for Emmet and Cheboygan Counties are largely in Gates and Ehlers' original list of the flora of the Douglas Lake region (1925) and their three supplements (1928, 1931, and 1948). Mackinac County records are more widely scattered; most of them are included in one or more of the references listed at the close of this paper.

Specimens representing the records presented herein for the *Botrychium, Spiraea, Sorbus, Satureja, Orobanche,* and *Galium* species have been deposited in the herbarium of the University of Michigan through Dr. Rogers McVaugh, to whom I am grateful for much valued advice and assistance.

Species marked with an asterisk in the following notes are new records for the counties from which they are reported.

**Botrychium lunaria* var. *onondagense* (Underwood) House

Emmet County. Several dozen plants in sandy soil less than a hundred yards back from the shore of the Straits of Mackinac, in section 12, Wawatam Township. Growing amid grasses and poison ivy, the ferns are very inconspicuous, and seem to be found particularly in the shade around low shrubs, such as *Shepherdia canadensis* and *Prunus pumila.*

This fern has been reported once for Cheboygan County (near Douglas Lake, Gates & Ehlers, 1925, p. 190). Clausen (1938, p. 67) cites a specimen from Mackinac Island in the Gray Herbarium, indicating erroneously that the Island is in Cheboygan County. The present report from Emmet County thus records this *Botrychium* from the third of the three Straits counties, and would suggest that it is generally distributed throughout northern Michigan, although very local in occurrence.

Varieties *onondagense, minganense,* and *typicum* have all been reported from Keweenaw County (especially Isle Royale) in the Upper Peninsula of Michigan (Cf. Beal, 1904, p. 35; Brown, 1937, p. 31; Clausen, 1938, pp. 65–67.)

**Salix interior* Rowlee (*S. longifolia* Muhl.)

Mackinac County. Occurs on Green Island, where *Salix* is also represented by the species *lucida, glaucophylla, bebbiana, adenophylla,* and at least one hybrid.

Laportea canadensis (L.) Gaud.

Cheboygan County. Grows in black, muddy soil in deep shade near the edge of Black River in section 22, Benton Township. *Geum canadense* occurs with this species, but there is little other herbaceous growth, as the ground is evidently subject to flooding. The species has previously been reported for the county only from east of Wolverine (Gates & Ehlers, 1928, p. 117).

Polygonum ramosissimum Michx.

Mackinac County. Sandy shore of Green Island. Previously reported for the county by Dodge (1921, p. 39) from sandy shore of Bois Blanc Island.

**Polygonum lapathifolium* L.

Mackinac County. Sandy shore of Green Island.

Salsola pestifer A. Nelson

Emmet County. Occurs along a dry gravel roadside in Springvale Township (sec. 36, T. 35 N.). Previously reported from Pellston (Gates & Ehlers, 1925, p. 239).

Corydalis sempervirens (L.) Pers.

Emmet County. On the pine-covered dunes in the southeastern part of Wilderness State Park. This species and *Cypripedium acaule* seem particularly characteristic of these dunes, growing through a carpet of pine needles. Reported "west of Pellston" (Gates & Ehlers, 1925, p. 231).

**Mitella diphylla* L.

Emmet County. Rather common in rich deciduous woods in Wawatam Township. Dr. Rogers McVaugh has found the species near Good Hart, where it occurs less abundantly, but in similar situations.

**Spiraea tomentosa* L.

Cheboygan County. Occasional along the sandy shores (east and south sides) of Devereaux Lake (sec. 29, Aloha Township). *S. alba* occurs in greater abundance around this lake, which is fringed with sweet fern, jack pine, and aspens.

**Sorbus decora* (Sarg.) Schneider

Emmet County. In woods in Wawatam and Bliss Townships. Most of the plants observed have been straight trees in young, predominantly deciduous woods with a coniferous element.

Several individuals grow in the woods along the bluff west of McGulpin Point (Wawatam Tp.), where the dominant trees include *Thuja* and *Abies* and where there is a thick undergrowth of small *Betula*, *Prunus*, *Amelanchier*, and *Cornus* species. Taller, straight specimens of *Sorbus* grow at the top of the bluff, and shrubby plants grow on the slope, where the soil is thinner. This bluff is about forty feet high, and about seven hundred feet in from the shore of the Straits; it is of limestone, marking the Nipissing stage of the Great Lakes, and is now heavily wooded.

The Bliss Township station is only a few yards from the shore of Lake Michigan (at Sturgeon Bay) and is also a mixed woods with several conifers.

Sorbus decora has probably not been previously reported for the county on account of confusion with *S. americana*, from which it may be distinguished "by its larger and later flowers, the broader, acute leaflets, and its much larger fruits." (Jones, 1939, pp. 28–29). The pedicels and peduncles of the inflorescences of the Emmet County *decora* are decidedly pubescent, as are the under surfaces of the leaflets.

This species has been reported from Mackinac Island (Mackinac County) by Dodge as *Pyrus sitchensis* in the addenda to his 1913 list, and also in his 1921 list; and by Beal as *S. sambucifolia* in his "Michigan Flora" (1904, p. 89).

Verbena stricta Vent.

Emmet County. A few plants found in very sandy soil in the valleys of sparsely wooded sand dunes in Littlefield and Little Traverse Townships. "One large clump" reported by Gates and Ehlers (1925, p. 252) along a road west of Pellston.

**Scutellaria epilobiifolia* A. Hamil. (*S. galericulata* L.)

Mackinac County. Scarce in low spots on Green Island.

**Satureja acinos* (L.) Scheele

Mackinac County. Several patches in dry sandy ground on the higher portions of Green Island.

**Orobanche uniflora* L.

Emmet County. Frequent in Wawatam Township near the shore of the Straits of Mackinac. It grows in slightly shaded situations, where it is parasitic on *Solidago racemosa* var. *gillmani* and probably other beach plants. There are several specimens of this species in the herbarium of the University of Michigan Biological Station. They were collected by Dr. Charles W. Creaser along "Wawatam Beach, west of Mackinaw City, 17 June, 1945", and evidently represent the same stations as those from which specimens here reported have come.

Galium asprellum Michx.

Emmet County. Reclining on vegetation along Carp River, in section 29, Wawatam Township, near the Conservation Department's dam. Reported from west of Pellston by Gates and Ehlers (1925, p. 271).

**Eupatorium perfoliatum* L.

Mackinac County. On Green Island.

**Carduus crispus* L.

Mackinac County. Several plants along a gravel roadside on the top of a bluff near the shore of the Straits, in section 15 (T. 40 N.), Moran Township.

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LETTERS FROM GERMANY BY A MID-WESTERN COLLEGE PROFESSOR

1867–1868

WILLIS A. CHAMBERLIN[1]

William Arnold Stevens, writer of these letters, was a young professor of Greek at Denison University, Granville, Ohio, who was studying at the University of Leipzig in 1867–1868. Being an ambitious student, he was not satisfied with the collegiate training simply, but had gone on into graduate work at Harvard and other institutions. After a few years of teaching he desired a still better preparation for his work and looked to the German universities as the best place for the fulfillment of his plans. He was granted a leave of absence for the purpose of foreign study.

The reputation of the German universities as centers of scholarship was well recognized in the United States by that time. From the days of George Ticknor and Edward Everett the flow of American students to Germany for advanced work had increased to a stream. Noteworthy among more recent representatives were William Dwight Whitney, eminent philologist of Yale, Andrew D. White, who introduced German methods into the University of Michigan and later into the organization of Cornell, and Daniel C. Gilman, who was to organize at Johns Hopkins the first American university after German models. Stevens knew these men by their works and their praise of the academic freedom and the thorough scholarship of the German professors spurred his ambition to try for himself these sources of wisdom. None of his colleagues had enjoyed this experience, and very few if any contemporary professors in Ohio colleges had the distinction of foreign study. So it was a new adventure on which he set out in March, 1867. He had already acquired some familiarity with the German language, before he left the home-land. He made this start probably with a fellow-student of German descent named Deckmann. Deckmann had served in the German army, then had come to the United States and entered Denison. With the faculty consent, he organized a class for the study of German in 1861, of which it is natural to assume that Stevens, then in his junior year, was a member. This brief experience with the language served him well, when he landed six years later on German soil.

The letters were written to his father, John Stevens, professor of the classical languages at Denison, whose versatile and vigorous hand in religious journalism and academic affairs had a large part in shaping the religious life of the west. Tied in a neat package and hidden away in a safety-vault, the letters were

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numbered and in perfect order when they were recently brought to light. They were written in a script resembling engraving in its regularity and clearness and were as legible as on the day they were penned. Their descriptions of the German universities and of the "Gemütlichkeit" of the German family life of that time present the very opposite of the picture of today, when Germany's "will for power" has reduced it to ruins.

In the political picture of Germany during the period of Stevens' study, Bismarck was in the foreground. With ponderous blows he was welding the separate states into the German Empire under the leadership of Prussia, whose King William was soon to become German Emperor. The preceding year, 1866, had witnessed the quick victory of the Prussian army over Austria in a "Blitz-Krieg," which left the way clear for the formation of the Nord-Deutscher Bund. Leipzig, in which these letters of the college professor were penned, was in Saxony, which was forced after the Austrian war into the League of North German states.

His first epistle was dated at Hamburg on April 2, 1867:

> "I hasten to inform you," he wrote, "of the completion of my voyage and safe arrival here yesterday. . . . The two days in the English Channel were delightful, and the views of the coast of England indescribably beautiful in places, though any land view would be attractive in sunlight and fair weather, after a rough sea voyage. When we emerged into the North Sea the weather again became rough, and we had little comfort till we passed Heligoland and entered the Elbe. We entered the river at night and early in the morning anchored about thirty miles from its mouth and forty miles below Hamburg. . . . As soon as the dawn permitted, I looked eagerly out of my state-room window and with what delight I gazed out upon the opposite shore of the river! It was land! It was the long wished for soil of Germany and the old world, that I was soon to set foot upon. . . . After partaking of a breakfast we seated ourselves in the neat little steamboat, which puffed cheerily along and quickly whisked us up the river. . . . You can hardly conceive what a warm inviting look the marshy flat banks of the river had. The sedge and marsh grass was not yet clothed with the green of spring, but even the dull yellow and brown were rich tints to those who had left the cold gray pitiless ocean. . . . All the past wearisome stormy days of the voyage were forgotten amid the crowding emotions of that yesterday morning. The pleasure derived from the new scenes was mingled with gratitude to Him who has thus far kept me safely and was now granting me the happy fulfillment of so many hopes."

He tarried in Hamburg only long enough to see some of the general features of the city, expecting to return in the summer. Then he pushed on to Leipzig, the old university town in Saxony. His letter of April 11 describes his journey and first impressions:

> "A railroad ride of thirteen hours brought me to Leipzig. Most of it was over a level country, the basin and lowlands of the Elbe. Wittenberg was the first considerable town that we stopped at, and here for the first time my baggage underwent a customs examination. In the Hamburg domain everything has free entry. The search was merely nominal in my case. I opened my trunk, unrolled a bundle or two, and that seemed to satisfy them.
>
> "In my coupé . . . for the first fifty miles I had an intelligent and interesting companion,—a Hamburg merchant going to attend the 'Reichstag' at Berlin. His enthusiasm was intense in the cause of German nationality and the rising power of the united German states. The new Confederation of North Germany embraces some twenty-five or more states, with Prussia at the head of them. The new constitution which they have about

settled on is similar in many respects to ours, though allowing a wider range to the local governments. My friend showed the general German dislike of Napoleon, as well as of England, but was warmly in favor of America."

He got down quickly to the study of German, hiring a private tutor. The above letter continues:

"I am busy now on German. I make use of all the opportunities I can to hear as well as talk it. I was complimented many times for my pronunciation and have no difficulty in making myself understood within the range of a limited vocabulary. But it is a 'big job' to master such a language and I have been often reminded with renewed force that one may read a language without actually getting into its life and spirit. I pay my German teacher, a 'Dr. Asher', a half thaler a lesson. The Prussian thaler, you know, is seventy-five cents, which, however, is now equal to a dollar of our currency. It was a satisfaction to get hold of a good instructor at once. I spend a full hour with him most every day; his talk to me and mine to him indeed, is in German. With an occasional necessary exception, we use no English, though he can speak and write well. He has a printed selection of idiomatic passages and sentences (English), which I make a written translation of and read to him. He then corrects pronunciation, words, arrangement and all."

About the University he writes:

"There are connected with the University here 110 professors, all put down to deliver lectures from one to six times a week on a subject, and some of them carrying on a half-dozen courses of lectures. As long as I remain here, how long that will be I am as yet wholly undecided, I shall make it my way to attend one or two courses. Curtius, the famous Grecian and philologist, is perhaps the greatest name here in the Philosophical Faculty. He is put down to deliver a course of lectures in explanation of difficult passages in Sophocles' *Antigone*. Ritschl has several courses of Latin lectures, but I shall not attempt to do anything more than hear the man once or twice, by way of curiosity."

He has still more to say in favor of the University of Leipzig in his next letter, dated April 24:

"I have not yet attempted any settled plan for the year to come, and it is not necessary. I am in a good situation here to get posted about literary matters generally, learn the language and pursue classical studies. The University of Leipzig ranks among the first in Greek and Latin and Philology, and I shall begin next week attending courses of lectures and continue to do so as long as I remain. I have procured catalogues, or lists of lectures rather, from the principal universities, and I find that none of them offer greater advantages than Leipzig, not even Berlin."

Mr. Stevens was especially fortunate in finding lodgings in the home of Dr. Karl Biedermann, a professor in the University. He had a comfortable room there and was treated like one of the family, which warmed his soul after living several years in the cheerless quarters of the dormitory at the Granville college. He describes his surroundings in writing to his father on May 2, 1867:

"When I wrote last week I was just going to my new quarters with Professor Biedermann. It has been a delightful change. I have a large, handsome, well-lighted room (besides bedroom), and am well attended to in every way. I take dinner regularly with the family, and sometimes tea, tho' not when it is pleasant out of doors. My breakfast I take in my room. My room, meals, light and fire, in the way that I am living now, will cost me some eight thalers a week. It is a little more expensive than I would have it in some places,

> but I have the advantage of meeting daily with an intelligent family, and a far better opportunity of learning the language. There are four children, two boys twenty-three and thirteen, two girls eighteen and twelve, and altogether a very agreeable little circle. They are obliging in helping me along in my talk and seem to take pains to make my sojourn agreeable."

Dr. Karl Biedermann was a noted journalist and political leader as well as professor. He was active in politics during one of the stormiest periods in German history, in which Prussia took the lead away from Austria and was forging the new German Empire. He was secretary and first vice-president of the Frankfort Parliament of 1848, which drew up a plan for a constitutional monarchy. He wrote an account of the revolutionary movement in a two-volume work entitled: *1840–1870, Thirty Years of German History.* He was a leader of the National-Liberal party in the Saxon legislature and worked for a united government under Prussia. On the formation of the Empire in 1871 he became a member of the Reichstag. He was the author of several important works, including an autobiography and a general history of the German people. He had a warm side towards American students, which showed itself in cordiality to them.

Stevens refers frequently to the pleasant relations he enjoys with this family. On one occasion he writes, (July 18, 1867):

> "I ought not omit mentioning how cordial and friendly a relation has sprung up between myself and the family that I have been dwelling with. With considerable perhaps that is not congenial, and especially with no religious fellowship, it would have been impossible for me to be indifferent to their warm-hearted and affectionate attentions. Mrs. B. has spared no pains to make my stay in Leipzig agreeable and in a thousand ways has made her house and home pleasant for me. She has as kindly a nature as can well exist, and with it more than an average share of common sense. Prof. B. by a letter of recommendation to a friend in Weimar, and by other information, contributed much to the value of my tour. It is certainly not my own wisdom, but a kind Providence that has led me thus far. My first three or four months in Germany have been more than doubled in value by my finding such a place. The assistance in learning the language has been invaluable."

With the Biedermanns Stevens found a warm and cheerful home-life, something that he had missed since his mother's death. It became his habit, after taking dinner with the family, to spend the evening with them in lively talk and in reading. He or some other member of the group frequently read aloud and in this way he gained fluency in the language and familiarity with German literature. This home was the brightest spot in all Germany to him and as often as he returned from some tour he came to this place as to a haven of rest. In February occurred his birthday, which the Biedermanns marked as a very special event.

> "A week ago was my birthday," he writes on February 12, 1868, "closing the 29th year. Coming out of my bedroom just at dawn, I found on my table the evidence that my friends here had not forgotten it. No birthday passes unnoticed in a German family. Each one had contributed a gift, and a couple of pots of flowers alongside of a tray of cakes bore the card, 'Wir gratulieren, Familie Biedermann.' It was also made the occasion of something extra at the dinner table, and though my temperance obstinacy made it somewhat one sided, the usual health was drunk in good champagne. You see these people over here cultivate the art of paying mutual kind attentions more than we do, and know how to throw a pleasant hue over a good many days for each other. We Americans, and especially the steady old

Puritan type that prevails in our family, are deficient in some branches of the philosophy of living."

Meanwhile Stevens did not lose sight of the main object of his coming to Germany. Having found a pleasant room and taken an intensive course in the German language, he proceeded to "hear" a course of lectures. As early as May 2 he began his work, of which he writes:

> "I have just come from the University where I have heard Georg Curtius, in his first lecture of his course on passages of Sophocles' ***Antigone***. I will at once give you an account of it. It was my first attempt to hear a University lecture here, except that yesterday I went with Professor Biedermann, whose house I live in, to listen to one from him on recent German history. That was interesting but not specially in my line, and I went partly to please him, and partly as a German exercise."

(A few lines about the gathering of the students during the "academic quarter-hour.")

> "About sixty students in all were present. Soon the door opened, the room became quiet, and Professor Curtius walked to the little raised desk, took out his notes, and without any prefatory remark began his lecture. He is a short, rather ungainly figure and thickset; he has a genuine German face, round and full, and a little 'frizz' of gray whiskers on each cheek. He looked genial and wide-awake, however, not nearly so old a man as I had expected to see. He is about sixty, I am told. He began with a voice somewhat squeaky and nasal, but pronounced distinctly, and whenever he referred to authorities, or made quotations from the Greek, he repeated the name, page, etc. He sat while delivering the lecture, and with his face turned most all the time to the right hand wall, looking down into the faces of his hearers sometimes, particularly when he uttered anything with a spice of pleasantry in it. His manner was vivacious and interesting throughout, and he was evidently full of his subject. A small blackboard hung on the wall behind the little pulpit in which he sat, and now and then he turned in his chair to write a word or syllable, illustrating the derivation and growth of a word. His auditors meanwhile listened most intently till the ten o'clock bell rang, when he finished the sentence he was uttering, folded up his notes and marched out. I was interested, and as intent a listener as any of those there, though of course here and there I had to lose the meaning in the midst of a long sentence. It has gratified me not a little to find, despite the difficulty of acquiring readiness in conversation, that I can understand lectures and public discourses so well."

Lectures by other professors were heard by him, especially those of Professor Friedrich Ritschl, the distinguished Latinist, of Professor Tischendorf, the famous scholar of Oriental languages, who had discovered the priceless Codex of the Scriptures in the convent on Mt. Sinai, and of Professor K. Hermann, who had a course on Comparative Grammar. He noted the characteristics and mannerisms of these men, which amused him. He followed closely some of Professor Biedermann's lectures on History and made outlines of them in German, but this was chiefly as an exercise in learning the language.

In midsummer he broke away from systematic study to gain time for travel and sight-seeing. Leaving Leipzig early in July he made a trip through Thüringen, of which we have merely a mention in this series, the account being written to his brother George. Then in the middle of the month he arrived in Berlin for a considerable visit. His purpose was "partly to see sights, partly to reconnoitre the ground for my special business, partly to study." He had nearly a month before the closing of the semester "to see and to hear some of these men and to make up my mind whether to spend the winter here." He spent many hours in the museum, where he was delighted to view the collections of ancient and modern art. "I have not been quite content ignorantly to gaze and admire," he writes, "and so have sought in a slight degree to inform myself and use the advantages therefor which Berlin affords. And, as I said, I have a glimpse of a new world."

In company of some relatives from Boston he made an excursion to Potsdam, viewing with great interest the memorials of Frederic the Great and the palaces of the reigning family. He was glad that he had leisure to study and examine these foreign scenes and needed not to rush from one city to another like most American tourists.

The Paris Exposition of 1867 was being held and Stevens decided to make an excursion thither and to get a cursory view of the city. So he left Berlin in mid-August, expecting to stay three weeks in Paris. By September 11 he is back again in Germany, stopping off a day in Magdeburg on his way to Leipzig. The bulk of his letter after his return is descriptive of Paris and the Exposition. "I came, I saw,—did not conquer," he says, "probably because I only began to see, for someone says that to see properly, includes the latter." He was greatly impressed with Paris and with the collections at the Exposition.

With just a day or two to rest he started out on a short tour of south Germany. His next letter was begun at Munich, where the Glyptotheka or Museum of Sculpture excited great interest in him. Although he had seen models of Greek art in Boston and elsewhere, here he stood before the actual specimens of classical sculpture from the age of Phidias and Praxiteles. The Museum itself, built in the style of a Greek temple, excited his admiration. Other places that he visited on this tour, which he mentions with only a brief reference to some historical event or comment on moral and political conditions, were Bamberg, Nuremberg, Augsburg, Regensburg, Prague and Dresden. Seventeen days were spent on this trip, at a cost of sixty thalers. Completing his letter in Leipzig he writes:

> "This letter will not afford space for any detailed descriptions, which I might with time and strength prolong endlessly. Some days have had more of enjoyment than others, but all have been rich and fruitful. Scenes gloriously beautiful in nature have left impressions never to be effaced, and scarcely less impressive have been the productions of human art. I can scarcely close my eyes without having the panorama unroll itself before me, reproducing the emotions of some hours not soon to be forgotten."

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> "The warmest words seem cold to express what I have felt, more than once during this last, as well as previous tours that I have made. One such hour was when I stood by a high castle ruin overlooking the Valhalla near Ratisbon (Regensburg) and the banks of the Danube. My soul was full, till I trembled, and tears were a relief."

The winter semester at Leipzig began late in October and Stevens was ready for a season of close application. On November 6th he writes that he is "fairly under way and steadily making some progress." He gave up the idea of studying Thucydides and focused his work on Homer, on whom Curtius gave a course. His lectures came four days a week. "Professor Curtius," he continues, "attracts me more than any German classical scholar I have seen. His writings have more of practical pointedness, and display a more careful selection than most of the German philologians."

This Professor Georg Curtius, whom Stevens so wisely chose as his intellectual guide and who exerted a profound influence upon him, was one of the shining lights of German scholarship. He was a scion of one of the cultured and ruling families in Germany, being the son of a famous syndic in the old free city of Lübeck. He enjoyed a liberal training at Bonn and Berlin. Under Ritschl, Bopp and other great philologists of his time he laid the foundations of his vast knowledge of Comparative Philology and the whole field of classical learning. He was graduated from the University of Berlin in 1842. His special aim was to bring the principles of the comparative study of Indo-Germanic languages to bear upon the classical languages. Before coming to Leipzig he had been professor at the University of Prague and the University of Kiel. His "School Grammar of Greek" was very famous and was used almost exclusively in Austrian schools. It passed into more than a score of editions. He was the author of another useful work for the study of Greek, his "Principles of Greek Etymology." This presented the Greek words and their parallels in all the related languages, so far as they were determined. It was this work which he suggested to Stevens to translate into English, to be mentioned later. He exhibited a friendly side to his students, whom he often entertained in his home. In these social hours he was assisted by his wife, who took a personal interest in their guests. Stevens was to enjoy the hospitality of this home in a marked way during the winter months of 1867–1868.

Invitations to Professor Curtius' home soon came to Mr. Stevens and he had the pleasure of meeting him more intimately than was possible in the lecture-room. On December 7 he describes quite fully one of these meetings *en famille*.

> "I took tea the other evening with Professor Curtius. There were present beside himself and wife only three others; two ladies and a Herr Angermann. The latter is a student at the University and the Professor's 'famulus'. The famulus is generally a sort of assistant or a private student by the professor, and attends to any arrangement between the lecturer and his hearers . . . .
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> "The evening which I have begun to speak of passed most pleasantly, though without any special incident. We had a plain meal at eight o'clock, not very unlike what we might have at home. Two kinds of wine, as is usual here, were offered, so I had again as on previous similar occasions to decline, and state my position. Professor C. is a neat and well-appearing man, and both he and his wife converse intelligently on a great variety of topics. They like, as do other Germans whom I have met, to hear about the peculiar features of American life.
>
> "As a scholar, his sound discrimination and practical judgment especially please me. His opponents in the philological arena charge him with a want of originality, that he does not produce much that is really his own. But his skill in selection and clearness in presenting the results of his studies are perhaps quite as valuable."

On New Year's day he was invited to dinner at the Curtius home. "He has shown himself very friendly," he wrote, "and I enjoy the opportunities of meeting both him and his wife." An invitation to New Year's dinner with a German professor is a distinction, of which he might well be proud and happy.

Stevens applied himself closely to his studies, keeping himself in fit condition by physical exercise several hours a week in the Turnhalle or gymnasium. With Professor Biedermann he took up fencing. "He is a practiced hand, and it affords a most convenient in-door recreation." With much and varied exercise he kept himself in good health and was stronger than at any previous time in his life. In a summary of the results of the first nine months he wrote on January 10, 1868:

> "It is gratifying to be able to report to you that so far the results of the past nine months are to me quite satisfactory. When I came abroad I felt quite uncertain as to the actual usable material that I could get hold of; whether I should not be lost amid the vast accumulations of scholarly labor. One thing I knew I could do, that was to study German and learn a spoken language. But the work of the last few months has been most satisfactory in my special studies, has solved many difficulties that had arisen before in my reading and study, and given me a sort of footing in the domain of philological study as now conducted. The study of the Sanscrit and the Gothic has been invested with unexpected interest. They mutually illustrate each other and the great family of languages to which they belong, the Greek quite as much as any. The Sanscrit, Middle Gothic, Greek and English, it sounds strange, does it not, to call them sister languages; but their features are not so radically different after all. The silver bound Gothic ms., which Dr. Warren[2] mentions as having been shown him when he visited Upsala in Sweden, is one of the most interesting literary relics in existence. It is a Gothic translation of most of the New Testament, and it is invaluable for the information which it gives concerning the language of which it is the chief relic remaining to us."

On February 12 he reported that he was again a guest at Professor Curtius' home:

> "Took tea again last evening with Professor Curtius and as usual had a most satisfactory time. Did not engage so much in the conversation myself, but was exceedingly interested in the discussions which arose of books and men in the department of Comparative Linguistics . . . .
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> "Professor Curtius is in his forty-eighth year. Ritschl is past sixty. The latter belongs to the old school, has had a wider personal influence than any other classical scholar in Germany, I presume. He and Curtius do not hitch together at all. Indeed the older philologians have no warm side towards the comparative studies that are now awakening so much attention. In Berlin they experience much opposition and the department there is not at all well represented. Haupt is at the head of the classical professors, practically, (in Berlin, I mean) and he adheres to the old methods very pertinaciously. But in my mind

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[2] This was Rev. J. G. Warren, who, it appears from correspondence in the *Journal and Messenger*, Baptist paper of Cincinnati, was appointed a delegate to Sweden, Denmark, Germany, etc. in 1867, to report on the state of the Baptist cause in those countries. He wrote several letters to the *Journal and Messenger* on this mission, in one of which, (October 31, 1867) he describes the Codex Argenteus, in the library at Upsala, Sweden. This Gothic translation of the Gospels, written in silver letters on blue vellum, dates from the fourth century, A.D.

> there is no question at all as to their growing value and importance, and I count myself very fortunate in being led to Leipzig, where the bearing of these studies upon the historical development of Greek receives special attention. It seems to me providential that I was brought here, for in spite of all my previous inquiries I had not been able to ascertain where my purpose could best be accomplished. In the multitude of scholars and books in Germany, I was at first quite at a loss precisely what method to follow in disposing of the limited time.
>
> "Although I have not yet seen a great deal of Professor Curtius, apart from his lectures, yet his acquaintance and advice have been most valuable. His lectures on Homer have also been most satisfactory. Both himself and wife have been very friendly indeed, especially as I was wholly strange and brought no letters of introduction with me."

On March 10, 1868, he reports that the semester closes that week, but he will have enough work in the Homeric poems to occupy his time for two or three weeks more.

> "I am now making some tolerably thorough notes with translation of the first portion of the *Iliad*," he writes. "My notes put in brief the result reached after comparing various authors. I do not pay so much attention to the historical and mythological explanations, which I can better bring up later. The character and derivation of words, points of syntax, questions of the text, etc., are what receive the most attention."

Former students of Professor Stevens will recall the emphasis he placed on the derivation and use of words, in his textual criticism. The passage above shows where he was confirmed in this habit. It was Professor Curtius' method applied by his apt student.

At the American consulate he was told that five hundred Americans were in Dresden. Stevens thinks that is an exaggeration, "yet the number scattered around in Europe studying music, art, etc. is larger than I had previously supposed. Many of them are poor representatives of our country and many of them do not employ their time to much purpose. Coming to Germany to study without a thorough preparation previously is of precious little use."[3]

In April, 1868, he was again in Berlin:

> "I have been revisiting the museums and other places of interest which became familiar to me last summer. The treasures and wonders of art and antiquity gathered in these Royal Museums exceed description. I rejoice in being able to make this second visit, making the pictures already impressed on my memory more clear and distinct."

On this visit he had the opportunity of attending the North German Parliament and of hearing Bismarck.

> "I attended the sittings for two days," he says. "Was especially glad to have an opportunity of seeing and hearing Count Bismarck. He took part in the debates a number of

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[3] Professor A. B. Faust in his work on *The German Element in the United States* (vol. 2, p. 231) estimates the number of American students in the philosophical faculty of German universities at seventy-seven in 1860, 173 in 1880. This estimate is based on Remsen's *Twenty-fifth Anniversary of the Johns Hopkins University*, p. 79. We may presume there were twenty to twenty-five students from the United States at the University of Leipzig in Stevens' time, although he does not nention them. Perhaps more were studying in the Conservatory of Music, well known even then.

> times. As soon as he rose, the whole assembly was hushed to perfect stillness. He is, however, 'no orator, as Brutus is.' In a plain, pointed style he expresses his opinion, and is done with it. He is large-built, robust, not corpulent; yet looks as if he suffered from high living, which is likely the case."
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> "Called twice on our ambassador Bancroft, but failed in finding him. I think it fortunate that we are represented here by a man who has lived and studied in Germany. Bancroft is doing us good service."

This was, of course, the historian, George Bancroft, United States Ambassador to Prussia, later to the German Empire, 1867–1874.

Back in Leipzig and with the Biedermanns, he reports on April 27, 1868, that:

> "Here in the house all goes on as pleasantly as ever, and in Professor Curtius' family I pass many an agreeable evening. Hardly a week passes that I do not take tea there, or make a long call toward evening.
>
> "When I so much wish for time to do a great many other things, there is some satisfaction in feeling that something has been done. In the Homeric language and literature I am vastly more at home. Have read both the *Iliad* and *Odyssey*, thus all that is properly Homeric. The German literature in this field is very rich, especially in the linguistic criticism. The explanation of history and customs has attracted them less. Gladstone, the great English statesman, has written three large volumes on 'Homer and the Homeric Age.' "

In the same letter he reveals that he is writing an article:

> "on the Science of Language, with the purpose of noticing its aims in contrast with philology, some of its methods and laws, its relation to other branches of study and the study of the classical tongues in particular. I thought it might perhaps be made popular enough to be suitable for the Baptist Quarterly, if good enough otherwise. As a sort of protective measure I am driven to be more productive. There must be some outgo in order to keep the mind in healthy activity."[4]

He was so convinced of the value of this scientific study of language, "Sprachwissenschaft," and so appreciative of Curtius' leadership in this field, that he applied himself almost exclusively to it during the summer semester of 1868. He was hard at work in May, when he wrote:

> "For myself I am well and my work progresses. By taking a great deal of exercise I counteract the effects of so much desk and book work. Am attending two courses of lectures

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[4] This article was completed and was published under the title: "Growth and History of Language" in the *Baptist Quarterly* (American Baptist Publication Society, Philadelphia) vol. 3, 1869, pp. 419–435. He distinguishes between philology and the science of language. Philology deals with the literature of any historic race, seeking to comprehend "its social, political and religious systems; in a word, the forces and phenomena of its culture and civilization. . . . The science of language, on the other hand, analyzes the phenomena of human speech."

A paragraph of this article is given as a good example of Dr. Stevens' clear and attractive style:

> "With cautious, but assured step, science is pressing on in this remote field of inquiry. A causeway of convincing fact is being pushed far back into a part that hitherto afforded no solid footing. We are, at least, brought nearer those beginnings of things towards which all science strives. The history of the mind of man, as revealed in language, its own work, must awaken increasing interest the more perfect its deliverances can be interpreted. Strange, how plainly the impalpable sounds, moulded in the viewless air, have retained imprints from the creative fingers of the mind."

> this semester, eight hours weekly. One is by Curtius on the Comparative Science of Language in its connection with Latin and Greek. The other is by Ritschl and entitled "Encyclopaedia of Philology," a general sketch of what has been done, and the doers of it, in the department of Classical Study. The exegetical lectures I have entirely left out, as they are none of them of the highest order, and I can get the results with less expenditure of time. My central subject of investigation just now is this 'Sprachwissenschaft,' specially in its bearings upon the development of Greek grammatical forms and Greek etymology. It is what I felt the need of years ago, though I knew not how it was to be got at, or what had been done in this direction. It was not a great deal that had been done. Curtius has accomplished by far the most in this line. His scholarship, as I have remarked in previous letters, is of a most admirable character,—clear, thoughtful, comprehensive. I am devoting more time to this Comparative Philology, as it is often called, than I had originally expected to do. But the increasing regard which it is gaining on all hands, and the character of its methods and results, convince me that it is destined to claim a larger share of attention from men of culture and in our courses of study. Within ten years there will be an advance in this respect. Accordingly, I am unwilling to lose the opportunity to get a fair start in it at the fountain-head, particularly as it bears on Greek. Professor Curtius in a most friendly manner gives me all the assistance that I ask for or need."

Friedrich Wilhelm Ritschl, mentioned above, born 1806, died 1876, was one of the most renowned classical scholars in Germany. Even in the Gymnasium in Wittenberg he was noted for his skill in writing and speaking Latin with clearness and assurance. He studied at the universities of Leipzig and Halle and was graduated *summa cum laude* from the latter institution in 1829. The period of his glory began with his call to a professorship at Bonn in 1839. He resigned this position in 1865 and was called to the University of Leipzig, where he spent the rest of his life. His aim in philology was "to reproduce classical antiquity by contemplation and recognition of all its expressions." Stevens, who had heard him the previous summer, described him thus:

> "He must be now considerably more than sixty years old. I found fifty or more students in the room, awaiting his entrance. He came in at a quarter after five, and had hardly stepped up to the little cubby-hole of a pulpit or desk, before he was underway with his lecture, beginning as usual with 'Meine Herren.' He has not the German head, and not their full habit. On the contrary his features are quite sharp, his nose acquiline in the most *extended* sense, and his whole countenance highly mobile. I noticed that he indulged largely in snuff, which has undoubtedly helped to injure his voice. He spoke in a cracked, piping voice, with a nasal tone; it was quite difficult to understand him, his voice not only falling frequently almost to a whisper, but his pronunciation being very indistinct for the lack of teeth. He appeared to have only two or three of these left. His genial manner and vivacity are, however, still evidently unimpaired. His eyes spoke and smiled with him, and his mouth was equally expressive, sometimes to a degree that was comical. His lips indeed seem to have been endeavoring to make up for the want of teeth, by a most extraordinary flexibility of manipulation, sometimes closing for a moment, and dilating till they answered to the definition of a line in geometry, (length without breadth or thickness) and then again puckering up till they almost reminded one of the corresponding definition of a point. . . . He is said to be very social and genial,—has a grown-up daughter who is highly educated, being versed in ancient as well as modern languages, an exceptional case in Germany. Girls here are better instructed in Modern Languages than those with us."

Stevens had studied Sanscrit all the winter semester with a private instructor, Dr. Windisch, who was recommended by both Professor Curtius and the professor of Sanscrit, Brockhaus. He wrote that he found "great satisfaction (and hard work) in digging into this new ground." His tutor, Dr. Windisch, was a professor in the Thomas-Schule, the celebrated Gymnasium in Leipzig in which Johann Sebastian Bach in his time directed the music. The famous boy-choir of the Thomas-Kirche is made up from boys of this school.

On one of his visits to Professor Curtius the subject of that scholar's work on Greek etymology came up and the author paid the highest compliment to Stevens' ability by suggesting that he translate into English this treatise. It was the crowning honor that came to Stevens during his residence abroad. That the famous professor had such confidence in his student's scholarship, that he could entrust to him the mediation of his monumental work to English students, was indeed a great distinction for the young American. He related it to his father with elation on May 16, 1868:

> "Thursday evening I had an unusually interesting conversation with Professor Curtius at and after tea. To pass over the rest,—I spoke of his work on the 'Outline of Greek Etymology,' a work in a large volume, containing not only a collection of Greek roots with their derivatives and their etymological relatives in different languages, but also the principles and methods of etymology in its application to Greek. It is a most valuable contribution to Greek scholarship, as is on all hands acknowledged. I expressed my regret that we did not have it in English. He said that Max Müller, who corresponds with him, had spoken of it a number of times, but nothing had been done, and that it was not the easiest thing to have such a work properly translated. Few were competent to do it without more revision and supervision on his part than he had time to bestow; indeed, that it could not be properly executed at all without consultation with the author on many points. Later in the evning in answer to the question whether the time of my return was fixed, I replied that it seemed to me necessary to be at home this fall. He wished that I might remain longer and asked if I could not turn it to financial account to translate or abridge in suitable form his book.
>
> "And so forth. I could not help thinking over the proposition on my way to my room, though too well aware that all things considered, my work at home would not allow me to spend even the part of another winter in Germany. I could not help thinking what a favorable opportunity it would be for me to give something to the public that would be of permanent and increasing value, give me a recognized place among scholars, which would help the college as well as myself in its classical work. You see, I occasionally have time to dream, as well as to peg away at study."
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> "What is all this worth?" he inquires later in the same letter, referring to his stay in Leipzig and after that a few weeks of travel in Switzerland and Italy; "I ask sometimes and look forward inquiringly, whether my *doing* shall be commensurate with my *opportunity*. I am not always able to distinguish between that endeavor after the most comprehensive and longest continued usefulness which results from the highest Christian wisdom, and that wide reaching effort which is more the result of a personal ambition. I need wisdom, the true,
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> 'Knowledge comes, but wisdom lingers'
>
> says Tennyson, and of the highest wisdom it is most certain that knowledge avails little to bring it. Generally I am trustful and hopeful, not always, however, I am painfully conscious of a loss of spiritual energy, which I feel nothing else can replace. He that giveth 'the more grace,' I need his gift."

He had to decline the honor of translating Professor Curtius' book, apparently on the ground of lack of time. He felt obligated to return to his teaching at Denison in the fall of 1868. His *alma mater* had granted him a year and a half, and he could not keep her waiting longer, even though he seemed to be breaking away "from this long-planned season of preparation for my life work." He brought Curtius' volume back with him, however, as one of his treasures and deposited it in the college library, where it is now seldom used in this "scientific age."

As only a few months remained of his visit to Germany, he was troubled over the question, whether to leave Leipzig in the middle of the semester, so as to gain time for a tour of Switzerland and a visit to Italy, or to stay on till near the close of the courses and forego the trip to Italy. The latter plan proved wiser and so he stayed at Leipzig, continuing his work until July 23. In the meantime he was at work preparing his article on the "Science of Language," which he hoped "might be hitched on to a discussion of Professor Whitney's work, or be an independent essay." He says he has "put together materials and written much of it with some care." Also, he selected books for the college library, for which a sum of $900 had been raised. He will go to London on his way home, so as to purchase more books there and to have a glimpse of England. His departure from Leipzig was preceded by noisy preparations, for a carpenter was called in to hoop with iron the "huge box of books, that he had packed."

> "I have laid out a little more here for the library than I had originally intended," he writes on July 21, 1868, "but was convinced that there would be no better opportunity of making a selection of German works, in person. . . . The whole amount laid out here reaches nearly $600. These are not all German, it is to be remembered; a portion are English, a large number editions of Greek and Latin classics, maps, etc. Taking $900 as the limit, I shall have in London nearly $250, after laying aside enough to pay all expenses in New York."

On Thursday morning, July 23, at half past four, he was about to start out. He sat down to write a few lines to his father, in which he expresses his mingled feelings:

> "At last I am ready to leave this room and this my German home. It is not strange that I linger over thoughts of the months that have been passed here; but this is not the place for them. My work in Leipzig is done and from now on my eagerness to meet you and see the home once more will increase."

His first objective was Switzerland, whose towering mountains and brilliant lakes made an unforgettable impression upon him. He made the journey afoot with a friend, whom he characterized as "a true man, a good companion, a lover of nature." They spent a month together "such as is granted to few. No shadow rests upon it."

Much to his regret he had to give up the idea of seeing Italy. The lack of time did not permit even a short journey to the Italian lakes. Contrary to his original intention, he determined to go back through Germany on his way to England. On August 26, 1868, he wrote his last letter from Leipzig, expressing his joy at being there:

> "Once more from this familiar spot I write to you, an unexpected pleasure. Arrived last evening after a continuous ride of nearly eighteen hours from Munich. Came in at eleven

o'clock. Professor Biedermann was away taking his vacation journey, but Mrs. B. and three of the children greeted me with German cordiality. Today I have been as it were at home."

He spent a fortnight in London, making the choice of books for the college library one of his chief concerns. Then he embarked on September 15th on the S. S. "Siberia" from Liverpool, arriving at Boston on September 26th. The voyage was uneventful and quick for that time, only ten days. Then he hurried on to Granville, stopping at New York only long enough to get his books through customs, for the college year had already opened. His expressed wish for his father to meet him with a horse and buggy at Newark, the nearest railroad point, and to ride home with him alone in the quiet hours of the night was overruled by the students, who sent a delegation of the senior class to meet him at the station and escort him to Granville. The welcome is described in the next issue of the college paper:

> "It affords us no ordinary gratification to announce the safe return of Professor W. A. Stevens, after an absence of more than a year and a half in Germany. At Newark a committee from the Senior class met and escorted him home.
>
> "We can only imagine his feelings as, just at dusk, he rode into the campus; but as the college bell, that faithful old monitor, announced his arrival with the same familiar ding-dong which had so often before called him to duty, we make bold to say that, while it awakened cherished recollections, for him there was a 'new song in its mouth,' more acceptable than ever. Such an affair is, by no means, an every day occurrence at Denison, and we must own up to some conjecture as to whether he would recognize us; whether he might not be more of a foreigner than when he left; and whether it might not be more natural for him to say, 'Wie geht's Ihnen?' than 'How do you do?'
>
> "But all our stand-offishness was soon dispelled, when instead of the 'distinguished stranger' we met him, face to face and hand to hand, as the same familiar friend, and were greeted in our own vernacular as cordially as in other days."

At once Professor Stevens resumed his work of teaching Greek, being now in charge of the department. To his professorship was added the position of Librarian. A busy and happy period of his life opened before him. Although the youngest professor in the faculty, he was respected as a thorough scholar, and he was a popular teacher. Unusual confidence was reposed in him by the trustees, so that when Dr. Samson Talbot, the president of the college, was laid aside by illness in 1873, Stevens was asked to take his place in teaching Moral and Intellectual Philosophy.

His teaching at Denison continued with great satisfaction to faculty and students until 1877, when he was called to a wider field as professor of New Testament Interpretation at the Rochester Theological Institution. He was the author of several books and articles. In conjunction with Dr. Ernest D. Burton, one of his former students at Denison, he prepared the *Harmony of the Gospels*, the book by which he is best known to the public. His teaching at Rochester was inspiring and he was recognized as an accurate and most reliable scholar.

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